

**UNIVERSITY OF SALENTO**

# Detailed Analysis of Renewable Energy-Based

# Desalination System for Maritime Vessels

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## Abstract

This report presents a detailed analysis of a network of buoys designed to produce electricity from renewable sources, which is subsequently used for water desalination. These buoys serve as replenishment points for maritime vessels, providing both desalinated water and energy. The goal is to optimize the management of energy production and water desalination to ensure efficient use of resources.

## 1. Introduction

The increasing need for sustainable and autonomous systems in marine environments has led to the development of buoys equipped with renewable energy sources and desalination capabilities. This report explores the dynamic model of such a system, providing a mathematical framework to describe the accumulation and utilization of energy and water over time.

## 2. System Description

### 2.1 Production and Desalination System

Each buoy is equipped with:

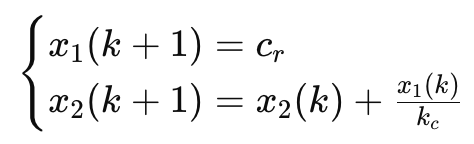
* **Energy Production System**: Converts renewable energy sources into electricity, denoted as cr​.
* **Battery**: Stores the generated electricity with a discharge efficiency rs​.
* **Desalination System**: Uses stored energy to desalinate water with an efficiency rd​.

## 3. Dynamic Equations

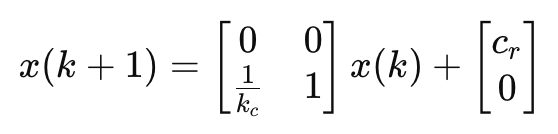
The system's behavior over time is described by a set of dynamic equations, which capture the evolution of accumulated energy and desalinated water.

### 3.1 First Case for Each Buoy

The first case considers the basic operation of the buoy without external interference:



In matrix form:

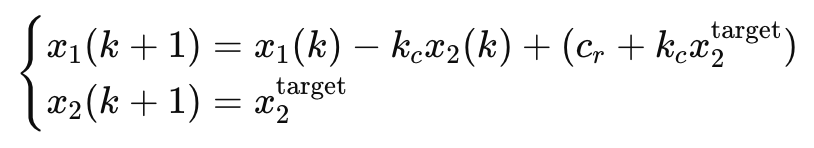


Where:

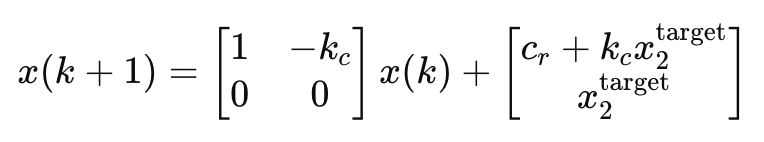
* x1​ represents the accumulated energy.
* x2 represents the accumulated water.
* cr is the constant amount of renewable energy available.
* kc is an energy-to-water conversion parameter.

### 3.2 Second Case for Each Buoy

The second case includes target values for water accumulation, introducing a more complex interaction:

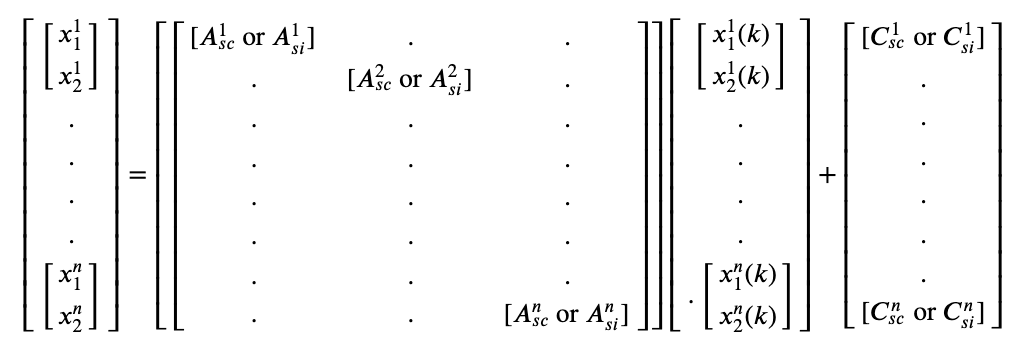


In matrix form:



## 4. Complete Case

Combining both scenarios, the complete model accounts for the state of multiple buoys:



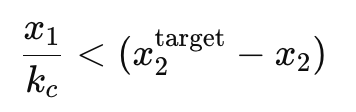
* **Asc**: Complete discharge scenario where all available energy is used.
* **Asi** ​: Incomplete discharge scenario where only part of the available energy is used.
* **Csc, Csi**: Vector of constant terms represents the fixed contributions of energy and water.

## 5. Hypotheses

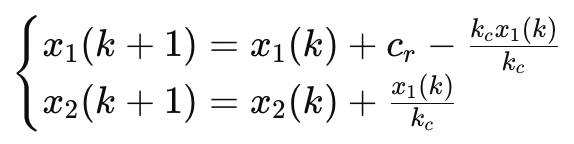
The system prioritizes water production, aiming to reach target values **x1target** and **x2target** ​. Two cases are considered:

### 5.1 Case 1 - Insufficient Battery Capacity

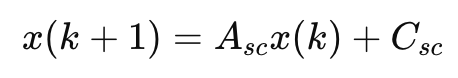
If the battery cannot recharge the entire tank, represented by the inequality:



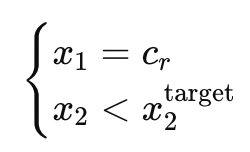
The dynamic equations are:



In matrix form:

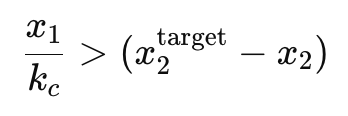


Resulting in:

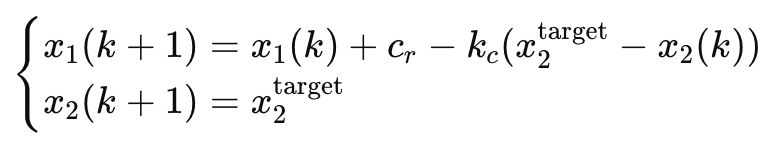


### 5.2 Case 2 - Sufficient Battery Capacity

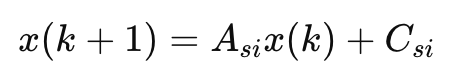
If the battery can recharge the entire tank:



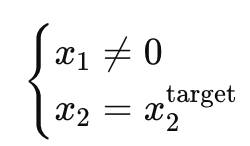
The dynamic equations are:



In matrix form:



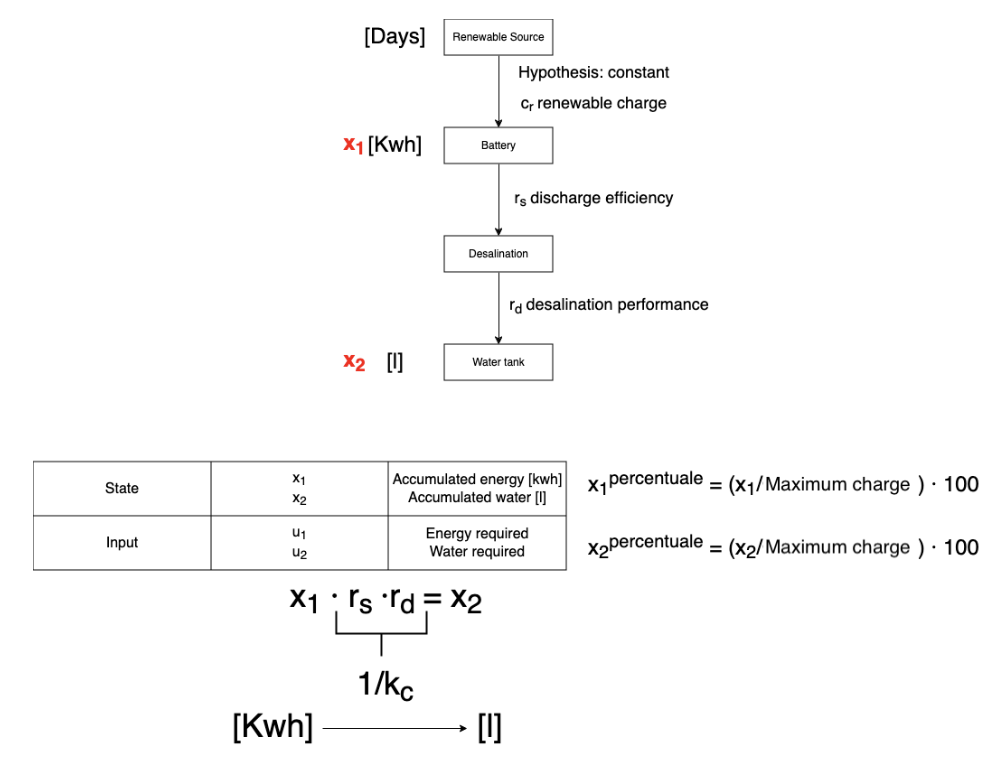
Resulting in:



## 6. Energy Flow Analysis

The energy flow diagram illustrates the transformation of renewable energy into water via the battery and desalination processes:

* **State Variables**: x1​ (Accumulated energy in kWh), x2​ (Accumulated water in liters).
* **Input Variables**: u1​ (Energy required), u2​ (Water required).



The energy flow diagram shows the transformation of renewable energy into water through the battery and desalination process:

1. Renewable energy cr.
2. Battery with discharge efficiency rs.
3. Desalination with efficiency rd.
4. Water accumulation in the tank.

Where the conversion is given by:

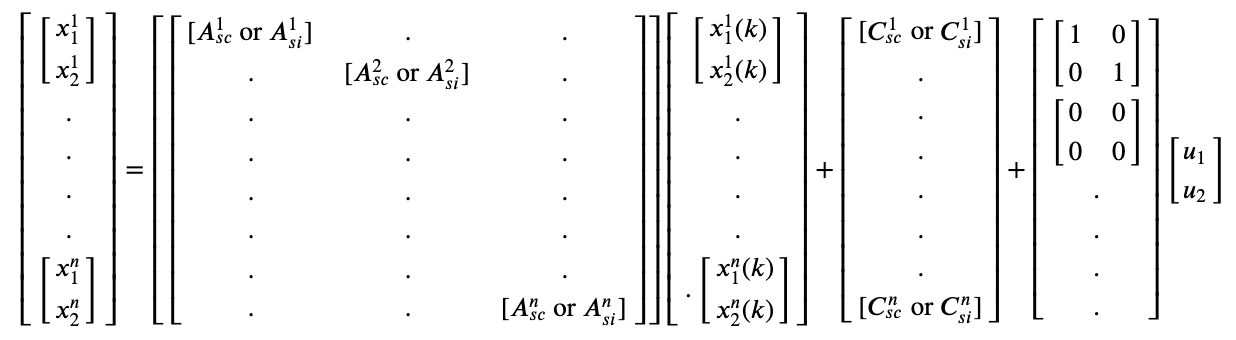


## 7. Considerations for Vessels

Vessels that go to the buoys to stock up on water and energy must be integrated into the model. You can think of adding variables that represent the quantity of resources taken from the boats:

* **u1**: Energy withdrawn.
* **u2**: Water taken.

The full model could then include these withdrawals in the dynamic equations:



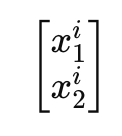
summarizing in detail:

### State of the Buoys

Each buoy has two state variables:

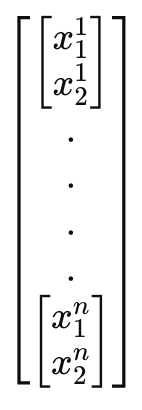
* x1i: Energy accumulated in buoy i at time k.
* x2i: Water accumulated in buoy i at time k.

These variables are collected in a column vector for each buoy:



### Complete System of Buoys

The complete system representation with n buoys is:

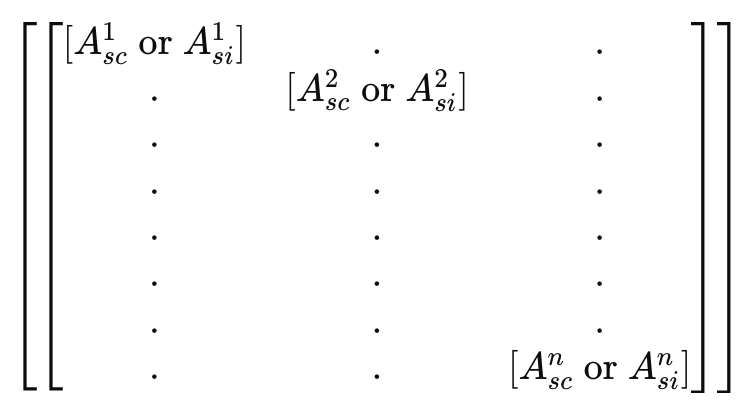


### Transition Matrix

The system dynamics are described by a transition matrix that can vary depending on whether there is a complete or incomplete discharge of the accumulated energy. This matrix is composed of sub-matrices **Asci​** or ​ **Asii**, where:

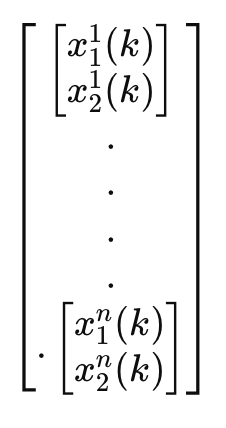
* ​**Asc**: Represents the case of complete discharge.
* **Asi**: Represents the case of incomplete discharge.

The complete transition matrix is:



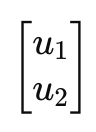
### State Vector at Time k

The state vector of the buoys at time k is:



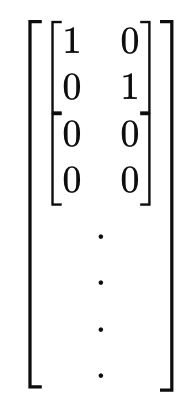
### Input Vector

The input vector represents the external contributions of energy and water required by the buoys:



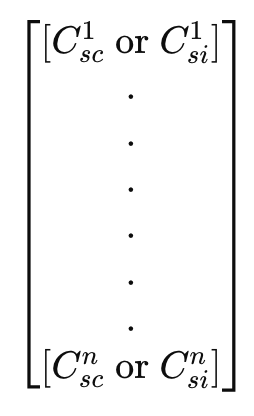
### Matrix Input Vector

The matrix that multiplies the input vector takes into account the resources withdrawn:



### Vector of Constant Terms

The vector of constant terms represents the fixed contributions of energy and water:



In summary, this matrix form represents the dynamic evolution of a system of buoys that accumulate energy and water, considering the internal dynamics of each buoy and the external contributions in terms of resources taken.

## 8. Code implementation

In implementing the code we opted for different scenarios, listed below:

1. Implementation of a single autonomous system consisting of 3 buoys with random generation of a number of vessels (for example a maximum of 2) per instant of time. The assignment occurs simply to the first buoy that has the resources available to satisfy the offer.
2. Implementation of three autonomous systems each consisting of 3 buoys with random generation of vessel requests for time slots, specifically:
   1. 02:00am – 05:00am: zero installments (0)
   2. 06:00am - 10:00am: low rate (1 to max\_vessels / 3)
   3. 10:00am -18:00pm: high rate (1 to max\_vessels)
   4. 18:00pm - 22:00pm: low rate (1 to max\_vessels / 3)
   5. 10:00pm - 06:00am: rate almost zero (0 to 1)

the assignment takes place at the first mark with available resources.

1. Implementation of a single autonomous system consisting of 3 buoys with random generation of a number of vessels (for example a maximum of 2) per instant of time. The assignment takes place according to a round robin criterion.
2. Implementation of three autonomous systems each consisting of 3 buoys with random generation of vessel requests for time slots, specifically:
   1. 02:00am – 05:00am: zero installments (0)
   2. 06:00am - 10:00am: low rate (1 to max\_vessels / 3)
   3. 10:00am -18:00pm: high rate (1 to max\_vessels)
   4. 18:00pm - 22:00pm: low rate (1 to max\_vessels / 3)
   5. 10:00pm - 06:00am: rate almost zero (0 to 1)

the assignment occurs according to a round robin criterion even between autonomous systems.

1. Implementation of three autonomous systems each consisting of 3 buoys with random generation of vessel requests for time slots, specifically:
   1. 02:00am – 05:00am: zero installments (0)
   2. 06:00am - 10:00am: low rate (1 to max\_vessels / 3)
   3. 10:00am -18:00pm: high rate (1 to max\_vessels)
   4. 18:00pm - 22:00pm: low rate (1 to max\_vessels / 3)
   5. 10:00pm - 06:00am: rate almost zero (0 to 1)

The assignment takes place according to the following method:

* Data Collection: Each buoy collects its own status data (available energy and water).
* Data Sharing: Buoys share their status data with other buoys in the system.
* Data Verification: Each buoy verifies the data received from the other buoys by comparing them with its own data and with the data received from other buoys.
* Data Consensus: Buoys reach a consensus on the correct data through a consensus protocol such as the Byzantine Generals Protocol.

This mode manages the possibility that some buoys may provide incorrect values ​​to every other buoy thanks to a completely distributed communication throughout the entire network of buoys, and also makes resource consumption efficient by maximizing it on each individual buoy.

1. It is an evolved version of problem 5 which exploits the problem of the Byzantine generals for the exchange of information between different autonomous systems, in this mode there will be a commander for each autonomous system who will then direct within his own autonomous system or will redirect to another.